INCLUSIVE AND SEMI-INCLUSIVE DEEP INELASTIC SCATTERING AT CEBAF AT HIGHER ENERGIES

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ABSTRACT

We summarize the discussion on the possibilities of doing inclusive and semi-inclusive deep inelastic scattering experiments at CEBAF with beam energy of the order of 10 GeV.

This summary is based on talks by A. Mueller and A. Schaefer and contributions of N. Bianchi, X. Ji, J.-M. Laget, P. Markowitz, W. Melnitchouk, Z.-E. Meziani, J. Milana, P. Mulders, S. Simula, P. Souder and M. Strikman. These contributions can be found elsewhere in this report.

Electron scattering from a composite target is due to an electroweak interaction, well-described by the exchange of a virtual boson, either a photon or Z^0. The exchanged particle carries a momentum q and probes the distribution of electroweak charges in the target which are carried by the (elementary) constituents, the quarks. Assuming that the momentum of the target is P, the invariant variables are the momentum transfer Q^2 and the energy transfer ν

$$Q^2 = -q^2 \stackrel{TRF}{=} 4E_e E_e' \sin^2(\theta_e/2), \tag{1}$$

$$\nu = \frac{P \cdot q}{M} \stackrel{TRF}{=} E_e - E_e'. \tag{2}$$

The momentum transfer is a spacelike vector. In the laboratory frame or target-rest-frame (TRF) these are simply determined by measuring the momentum of the incident and scattered electrons.

Deep inelastic scattering assumes that the electron resolves the quark structure of the nucleon. This requires a sufficiently high momentum transfer to be able to understand the reaction mechanism in terms of perturbative QCD process. A momentum transfer $Q > 1$ to 2 GeV is considered as the typical lower boundary for deep inelastic scattering. Transforming this into a spatial resolution, $\lambda \approx 1/Q$ gives $\lambda = 0.1$ - 0.2 fm. The deep inelastic scattering corresponds to a an incoherent sum over scattering off the individual quarks weighted by the squared charges. Besides the momentum

Figure 1: *The kinematic $Q^2 - \nu$ region accessible with a beam energy of 8 - 12 GeV (left of indicated lines). Shown are lines of constant x and constant W.*

transfer, one requires that the invariant mass W of the hadronic system is above the region of discrete baryon resonances, $W \geq 2$ GeV. The invariant mass W is given by

$$W^2 = (P+q)^2 = M^2 + 2\,M\nu - Q^2 = M^2 + \frac{1-x}{x}\,Q^2, \tag{3}$$

where x is the Bjorken scaling variable $x = Q^2/2P \cdot q$. The variable x can be interpreted as the fraction of the lightcone momentum of the struck quark compared to that of the nucleon,

$$x = \frac{p^+}{P^+} \tag{4}$$

Note that p is the quark momentum and $p^+ = (p^0 + p^3)/\sqrt{2}$. The two constraints ($Q > 1$ GeV and $W \geq 2$ GeV) restricts the experimental explorations at CEBAF to $1 \leq Q^2 \leq 10$ GeV^2 and $0.1 \leq x \leq 1$ for deep inelastic scattering on a nucleon. Fig. 1 shows the the specific domain accessible at CEBAF. Shown are furthermore lines of constant x for $x = 10^{-2}$, 10^{-1}, 1 (elastic scattering off a nucleon), 200 (elastic scattering off a heavy nucleus with $A = 200$), constant $W = M_\Delta$ (dashed, labeled Δ), 2 GeV (dashed, labeled N^*) and W corresponding to the threshold for J/ψ production (dashed, labeled c). The *region of deep inelastic scattering* is bounded by $W = 2$ GeV and the horizontal dot-dashed line corresponding with $Q^2 = 1$ GeV^2. The region between the (dashed) lines for $W = M_\Delta$ and $W = 2$ GeV is the *resonance region*. The right edge of the figure corresponds to $\nu = 200$ GeV, which is about the maximum energy transfer in the CERN muon experiments. The measurement of the

valence quark structure of hadrons and the correlations between quarks and gluons by deep inelastic studies have been extensively discussed in the review of Sloan, Smadja and Voss [1], in the Pegasys proposal [2] and the ELFE proposal [3].

1. The nucleon spin structure

In the study of valence quarks, which carry a sizable fraction of the momentum of the nucleon, an illustrative example of the possibilities at CEBAF is the determination of the precise shape of the polarized structure functions g_1^p and g_1^n at large x-values. Present available data on the neutron spin structure function at high Bjorken variable x stop at a value of 0.5. The precise shape and the threshold behavior for $x \to 1$ does not affect the sum rule but it *is* important for the comparison with model calculations of the quark distributions.

In order to test the prediction $A_1 \to 1$ as $x \to 1$ precision data at $x > 0.5$ are necessary. Furthermore, the slope with which the asymmetry reaches unity becomes sensitive to the details of the nucleon substructure. Severals constituent quark models although constrained by the limit at $x = 1$, produce an asymmetry A_1 which behaves differently in the large x region.

From the experimental point of view, measurements of A_1 at high energy are not feasible, because high x implies high E' (usually more that 10 GeV) the resolution of the high energy spectrometers does not allow a precise measurement of the slope since data are averaged over a wide x range. The low count rate conspires to make the measurement extremely difficult.

Therefore, it has been proposed to use the combination of unique possibilities of a high resolution 8 GeV incident electron beam and the Hall A spectrometers at large scattering angles. This implies a large recoil energy and therefore small E', typically below 4 GeV. The high momentum resolution of Hall A spectrometers allows to step in the x region between 0.2 and 0.7 finely keeping W^2 greater then 4 GeV^2 to insure that the scattering process is in the deep inelastic region. The depolarization factor for a given x is closer to one at large angle putting CEBAF at advantage for the measurement using large angle since $A_1 = A_{1\|}/D$. Two identical spectrometers with 10% momentum acceptance allow to double the solid angle from 7.5 to 15 msr. When combined with a 40 cm long high pressure polarized ^{3}He target and a 15 μA electron beam this setup offers a superb luminosity of $10^{36}/\mathrm{cm}^2/s$.

The proposal discussed by Meziani at this workshop showed that in 1000 hours of beam time one can achieve a precise measurement of the neutron spin structure function at high x.

2. Parity violation

It was proposed that a parity violation experiment in the deep inelastic region would be of special interest for $x = 0.5$, $y = 0.5$. Such a measurement would allow a precise test of the axial-hadron vector-electron electroweak coupling. The particular

point above will be less sensitive to structure functions, while measurements for lower x and y values are expected to provide information about structure functions.

3. Nonleading structure functions

The ratio of longitudinal and transverse cross sections $R(x, Q^2)$ (at relatively small Q^2) is nonzero as a result from a combination of perturbative QCD corrections, which are sensitive to the gluon distribution, higher twist corrections such as target mass corrections, and finally nonperturbative effects. Besides the study of R for a nucleon target, the study of R_A in a nucleus is of interest.

Another topic which we mention is the study of higher twist structure functions. These are of interest because they are a manifestation of correlations between quarks or between quarks and gluons. These correlations vanish as powers of $1/Q$ and are therefore more prominent at relatively small values of Q^2 (although one must be in the deep inelastic region!). In inclusive unpolarized electron scattering the first higher twist contribution is $\mathcal{O}(1/Q^2)$. At $\mathcal{O}(1/Q)$ higher twist contribution can be measured by using polarized beams and/or the detection of produced hadrons. As compared to the leading contribution the higher twist contributions turn out to be stronger at larger x-values, as shown in NMC experiments at CERN.

4. Semi-inclusive experiments

A region, where deep inelastic experiments are less restricted by energy considerations is the region of $x \geq 1$, accessible in scattering off nuclei. Here the beam luminosity is much more important, as the cross sections are small. After all, one is looking at one out of six valence quarks which carries a large fraction (more than 1/2) of the momentum of two nucleons, or one is looking at a quark belonging to a high-momentum nucleon in the nucleus. The distinction between these two can be made as in the second process one can try to detect another high-momentum nucleon or nuclear rest-system moving in the backward direction. These type of experiments (tagged structure functions) requiring high luminosity and special detector set-ups are well suited for an upgraded CEBAF.

The case of tagged structure functions is an example of a semi-inclusive process in which one (or more) particles are detected in coincidence with the scattered electron. For semi-inclusive processes one distinguishes different production mechanisms such as *target fragmentation* and *current fragmentation*. The latter case, in which one is interested mainly in the particles produced in the forward direction, can at sufficiently high energies be described as a product of quark distribution functions $f_{H\rightarrow q}(x)$ and quark fragmentation functions $D_{q\rightarrow h}(z)$. Here $z = P \cdot P_h/P \cdot q$, which in the target rest-frame is $z = E_h/\nu$, i.e. the fraction of the energy of the photon or the struck quark taken by the produced hadron. The fragmentation can be used to tag specific quark flavors or their spins, e.g. an s-quark will favor production of K^- (or $\overline{K}^0$) while an $\overline{s}$-quark will favor production of K^+ (or K^0), leading to asymmetries in

hadroproduction of specific particles (that must then be identified). In order for the factorization to be valid and have a sufficiently clear separation of the target and current fragmentation region, an energy of 10 GeV is too low[1].

5. Conclusions

The region, which for CEBAF is most important is the transition between the (inclusive) deep inelastic scattering region and the region of exclusive processes, such as the excitation of baryon resonances leading to a specific final state. In exclusive processes the momentum transfer in the t-channel becomes a relevant variable that determines if one can use perturbative QCD methods to describe the process. In this case the object of study are not the quark probabilities in the target, but one is sensitive to the (lightcone) quark wave functions, which depend on the lightcone momentum fractions $x_i = p_i^+/P^+$ and the perpendicular quark momenta. Focussing on elastic processes or exclusive or semi-inclusive production of vector mesons (ρ, ϕ or J/ψ one can investigate different components of the wave functions or specific reaction mechanisms.

An upgrade of energy up to about 10 GeV gives a relatively limited access to the region of inclusive deep inelastic scattering and even less to the region where semi-inclusive deep inelastic processes factorize. However, this workshop has shown that such an upgrade of CEBAF beam energy would allow to address a number of fundamental questions related to the valence quark structure of hadrons. The answers could clarify some puzzles related to the approach to scaling even at modest Q^2-values. For this a broad coverage of the resonance region reaching into the deep inelastic scattering region is important. It is here where the challenge is to connect effective hadronic theories or successful quark models to the underlying theory of quantum chromodynamics.

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2. *PEGASYS proposal* (blue book), IY-112 (1988);
3. *The ELFE project, an electron laboratory for Europe*, Proceedings of the conference on Physics with a 15-30 GeV High Intensity Continuous Beam Electron Accelerator, Mainz, 7-9 October 1992, edited by J. Arvieux and E. De Sanctis, published by the Italian Physical Society, Bologna, Italy.